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Abstract
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Keywords
Nondestructive Evaluation, Mechanical Engineering

THE DETERMINATION OF TENSILE STRESSES USING THE TEMPERATURE DEPENDENCE OF ULTRASONIC VELOCITY

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ABSTRACT

The effects of applied tensile stresses on the temperature dependence of 10 MHz ultrasonic longitudinal velocity have been studied in three types of commercial aluminum alloys, 6064-T4, 2024-T351, and 3003-T251. In all measurements, it is found that the velocity decreases linearly with temperature, and the slope of the linear relationship changes considerably as a function of applied tensile stresses within the elastic limit of the specimen used. Furthermore, the results indicate that the relative changes in the temperature dependence of the velocity due to stress is insensitive to composition and texture, and the data obtained on the different types of aluminum alloys can be represented by a single relationship. The sensitivity of the temperature dependence of the ultrasonic velocity to applied elastic stress is estimated to be ± 8 MN/m^2 which compares favorably with those obtained by other techniques.

INTRODUCTION

There is a general agreement that ultrasonic methods appear to hold the best promise in the nondestructive measurements of bulk stresses in both crystalline and non-crystalline materials.[1,2] Calculations have shown that ultrasonic velocity changes are linear functions of applied stress and unknown stresses can be determined when both the velocity in the absence of stress as well as third-order elastic constants are known independently. The measured velocity, however, strongly depends on microstructural features which makes it necessary to develop a calibration between velocity and stress in order to be used in the determination of unknown stresses. In addition, development of preferred orientations (texture) during deformation or fatigue, severely modify the third-order elastic constants. These problems can be solved when the differences between velocities of shear waves polarized perpendicular and parallel to stress directions are used. Due to these differences, a shift in phase will occur, and the out-of-phase components will interfere and cause a change in intensity. This method, however, does not have at present enough sensitivity, and requires an accurate determination of the shear velocity in the absence of stress.

Basically, the temperature dependences of the elastic constants of a solid are due to the anharmonic nature of the crystal lattice. A measure of the temperature dependence of the ultrasonic velocity can, therefore, be used to evaluate bulk stresses. Experiments undertaken on aluminum and copper[3,4] elastically deformed in compression showed that the ultrasonic velocity, in the vicinity of room temperature, changed linearly with temperature, and the slope of the linear relationship changed considerably as the amount of applied stress was varied. In aluminum, the relative changes of the temperature dependence of longitudinal velocity increased by as much as 23% at a stress of approximately 96 MPa. The linear relationship between the temperature dependence of the ultrasonic velocity and the applied stress was then used to determine the change as a function of distance of the tangential component of the stresses developed when an aluminum rod was shrunk fit into a slightly smaller hole drilled into an aluminum disc. Excellent agreement was obtained between the computed stress distribution, and that measured using the temperature dependence method.

In this paper, the effect of tensile elastic stresses on the temperature dependence of the longitudinal ultrasonic velocity has been studied in three aluminum specimens of types 6064-T4, 2024-T351, and 3003-T251. The results obtained on these specimen show that the relative change in the temperature dependence of ultrasonic velocity is a linear function of the amount of elastic tensile stress applied. The results also indicate that the changes in the temperature dependence due to stress is insensitive to composition and texture, and the data obtained on the different types of aluminum alloys can be represented by a single relationship.

EXPERIMENTAL

The ultrasonic velocity was measured on three aluminum specimens of types 6064-T4, 2024-T351, and 3003-T251 at temperatures ranging between 230 and 280K, using the pulse-echo-overlap method. Figure 1 displays the experimental system used in this work, which is capable of measuring changes in the ultrasonic velocity with an accuracy of better than 1 part of 10^5. This system has been described in detail elsewhere[5]. The velocity measurements were made while the specimen was subjected to various amounts of tensile stresses using the arrangements shown in Figure 2. In this arrangement, the specimen is gripped in an Instron machine where a predetermined load is applied and its value is kept constant during the entire velocity measurements.

RESULTS

In all measurements, the velocity was found to decrease linearly with temperature, and the slope of the linear relationship decreased as the amount of applied tensile stress is increased within the elastic limit of the specimen. A typical example of the results obtained on the type 3003-T251 aluminum is shown in Figure 3, where the longitudinal velocity is plotted vs temperature at stress 0, 32.8, 48.6, and 85.1 MPa. The values of the temperature dependence of ultrasonic velocity (dV_ℓ/dT) obtained

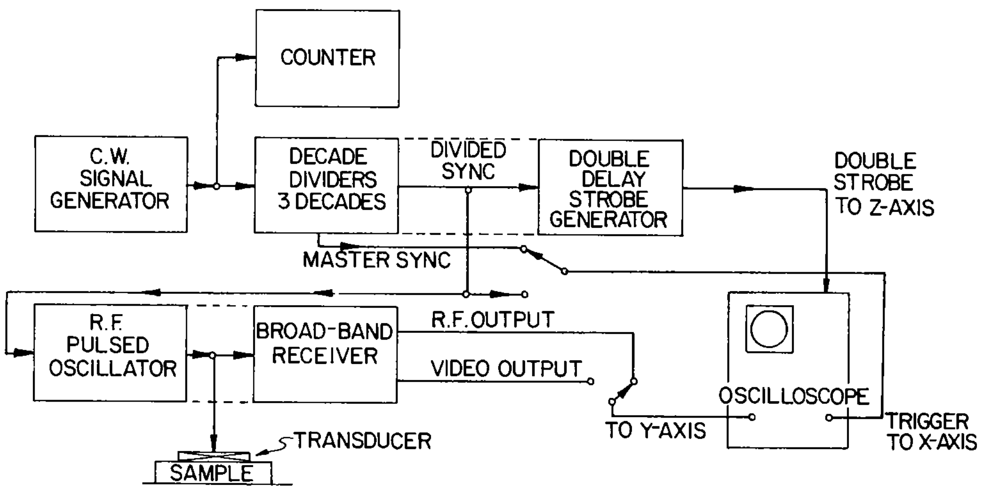

Fig. 1. Pulse-echo-overlap system for measuring ultrasonic velocity.

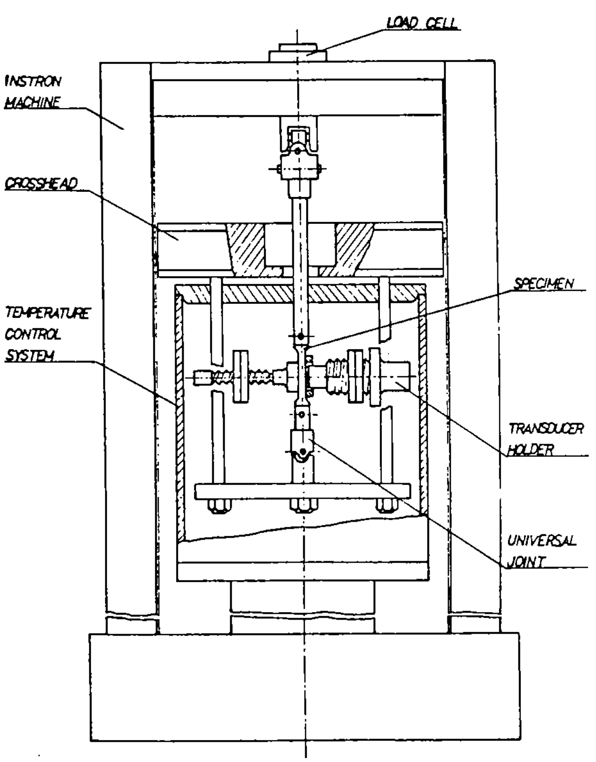

Fig. 2. System used for the application of stress during the ultrasonic measurement.

at various amounts of stress on the three specimens are listed in Table I. Because the values of (dV_ℓ/dT) at zero stress were found to vary from one type of aluminum to the other, the relative change in the temperature dependence, Δ, due to the application of stress was calculated, and its values are listed in Column 4 of the Table.

TABLE 1

Variations of the Temperature Dependence of Longitudinal Ultrasonic Velocity with Applied Tensile Stress in Aluminum

Specimen	Applied Stress (MPa)	-dV/dT (m/s k)	%
6060-T4 #1	0	1.304	0
	36.5	1.205	7.59
	60.8	1.155	11.44
	91.2	1.091	16.33
2024-T351 #2	0	1.187	0
	24.2	1.137	4.2
	73.0	1.073	9.6
3003-T251 #3	0	1.251	0
	32.8	1.167	6.7
	48.6	1.117	10.7
	85.1	1.039	16.9

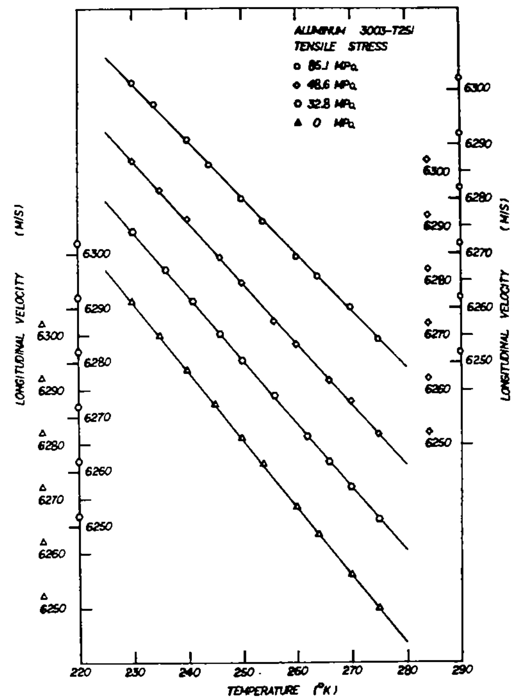

Fig. 3. Effect of applied tensile stress on the temperature dependence of ultrasonic longitudinal velocity in aluminum. Stress is applied in a perpendicular direction to the direction of propagation of the ultrasonic waves.

The relative changes in the temperature dependence $[(dV/dT)_\sigma - (dV/dT)_0]/(dV/dT)_0$ obtained on the three specimens are plotted as a function of applied tensile stress in Figure 4. The figure shows that the data points can be represented by a straight line which passes through the origin. This indicates that, regardless of the type of aluminum used, the relative change in the temperature dependence is a linear function of the applied stress and can be represented by,

$$\frac{(dV/dT)_\sigma - (dV/dT)_0}{(dV/dT)_0} \qquad (1)$$

where K is a constant equals 1.9×10^{-3} per MPa (1.3×10^{-2} per KSI). This value of K is about 20% smaller than that obtained when compressive stresses are used in the measurements.

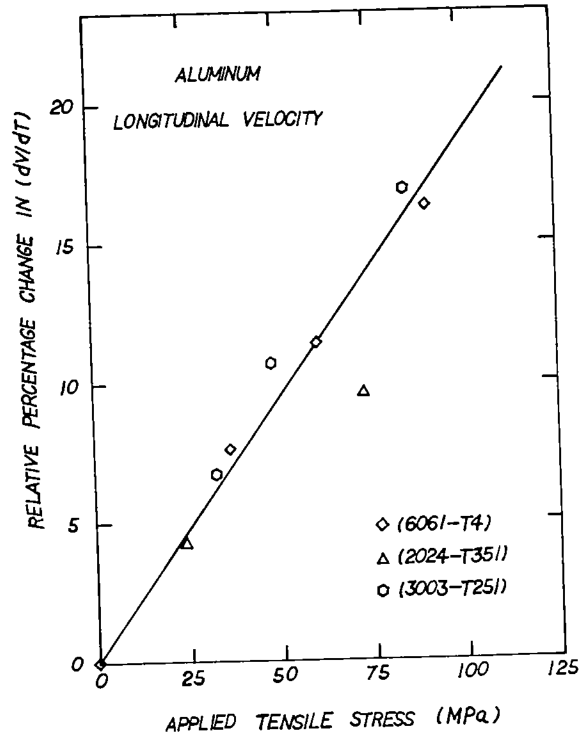

Fig. 4. Percentage of the relative change in the temperature dependence of ultrasonic longitudinal velocity as a function of applied stress in aluminum.

ACKNOWLEDGEMENT

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SUMMARY DISCUSSION

Martin Scott (Stanford): What was the temperature range in your measurement?

Kamel Salama (University of Houston): We measured from about 280 down to 220K. We are in the process of using higher temperature that goes from 300 degrees to 350 or 360K. Usually, somewhere between 50 and 70 degrees is quite adequate to give you a good determination for the slope of the velocity as a function of temperature.

Christian Burger (Iowa State): You were making your measurements through the thickness, so you were essentially looking at the plane-stress problem?

Kamel Salama: In all cases used in the calibration, the stress applied turned out to be axial. The component of stress which affected the change in the temperature dependence is the axial component. We confirmed this conclusion by having a specimen in an Instron machine where you are applying a pure uniaxial stress and do the velocity temperature measurements, and, as I said, it was about 15 percent smaller than what we got in the previous measurements.

Christian Burger: My difficulty is really with this interference problem you have on the board. How did you get rid of interference?

Kamel Salama: These measurements were done using shear waves. We made three measurements, one longitudinal, which turned out to be constant, where the temperature dependence had no change - or no considerable change as a function of the distance. The second measurement was where the particle velocity was in the tangential direction, the third measurement was where the particle velocity is toward the radius. And these measurements were obtained from the temperature dependence where the particle velocity is perpendicular to that line.

Christian Burger: Thank you.

William Pardee, Chairman (Science Center): I would like to offer Professor Salama my congratulations. We are less than 15 minutes behind, inspite of having one extra talk. There has been some complaint at previous sessions that the stampede towards the door at the end of the session has made it impossible to hear the questions. I would ask you to offer the last Speaker the courtesy of a few brief questions, if necessary.